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(54) Abstract Title: **Vehicle control according to road flatness indices**

(57) A method of controlling a motor vehicle (10 see fig 1) comprises estimation of two road flatness indices and determination of a road pitch and a roll angle. A control system 18 comprises a controller 26 which receives inputs from wheel speed sensors 20 and sensors for yaw rate 28, lateral acceleration 32, roll rate 34, longitudinal acceleration 36 and pitch rate 37. The indices may be used in the determination of the road pitch slope and the road bank angle. The indices may be functions of a relative roll angle or a relative pitch angle. Steady state roll and pitch angles may also be calculated. The system 18 may control or activate an active brake control system 41, an active front or rear steering system 42,43, an active anti-roll bar system 45 or an active suspension system 44, in response to the bank angle and pitch slope.

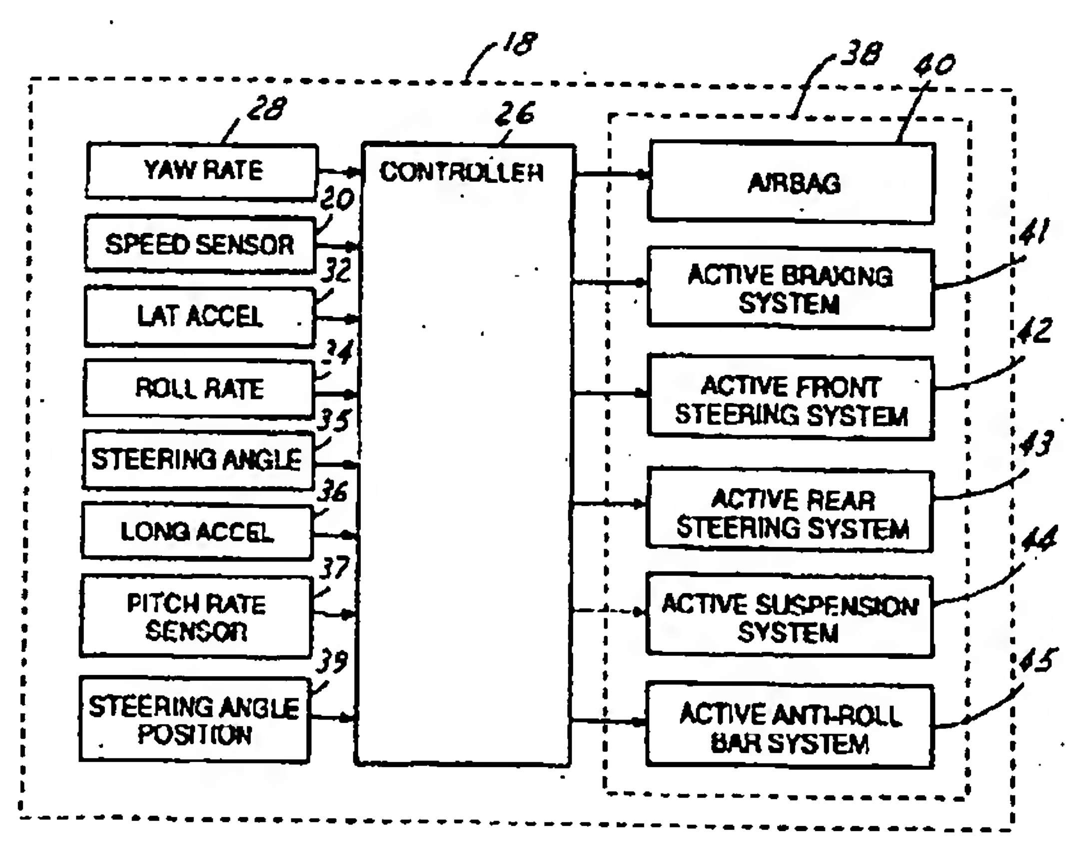

FIG. 4

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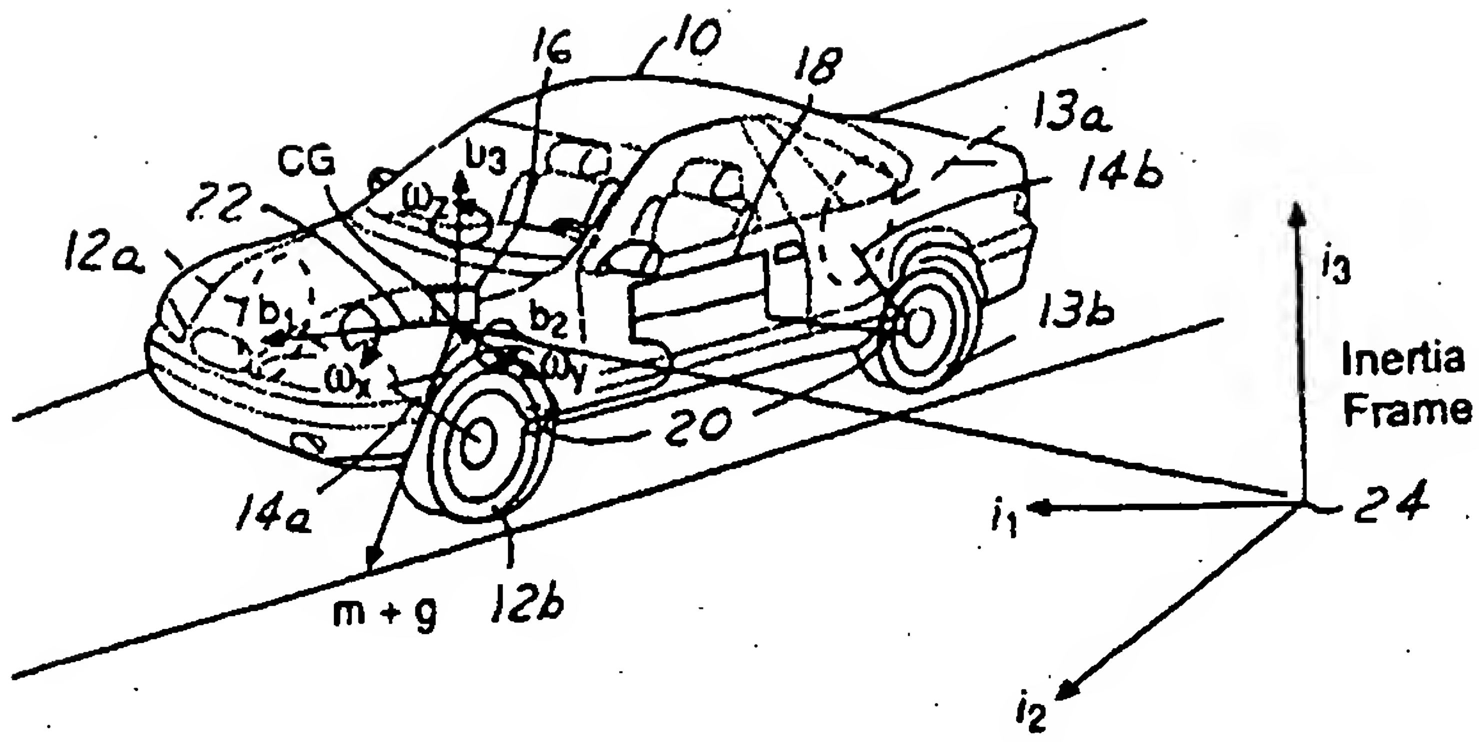
16
10
18
13a
14b
CG
22
12a
13b
Inertia
Frame
20
14a
24
m + g
12b

FIG. 1

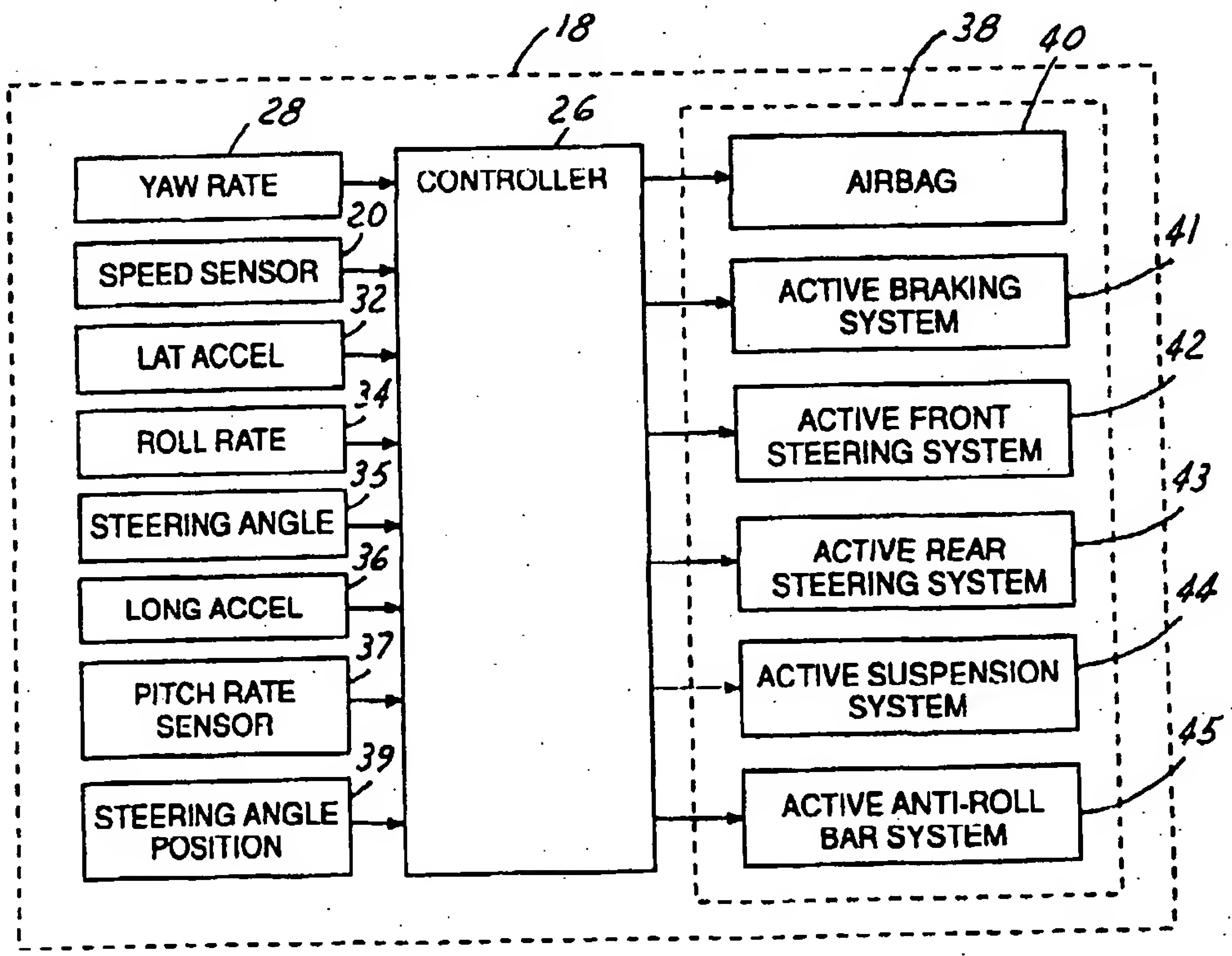
18
38
40
28
26
YAW RATE
CONTROLLER
AIRBAG
20
SPEED SENSOR
41
ACTIVE BRAKING
SYSTEM
32
LAT ACCEL
42
34
ACTIVE FRONT
STEERING SYSTEM
ROLL RATE
35
43
STEERING ANGLE
ACTIVE REAR
STEERING SYSTEM
36
LONG ACCEL
44
37
ACTIVE SUSPENSION
SYSTEM
PITCH RATE
SENSOR
45
39
STEERING ANGLE
POSITION
ACTIVE ANTI-ROLL
BAR SYSTEM

FIG. 4

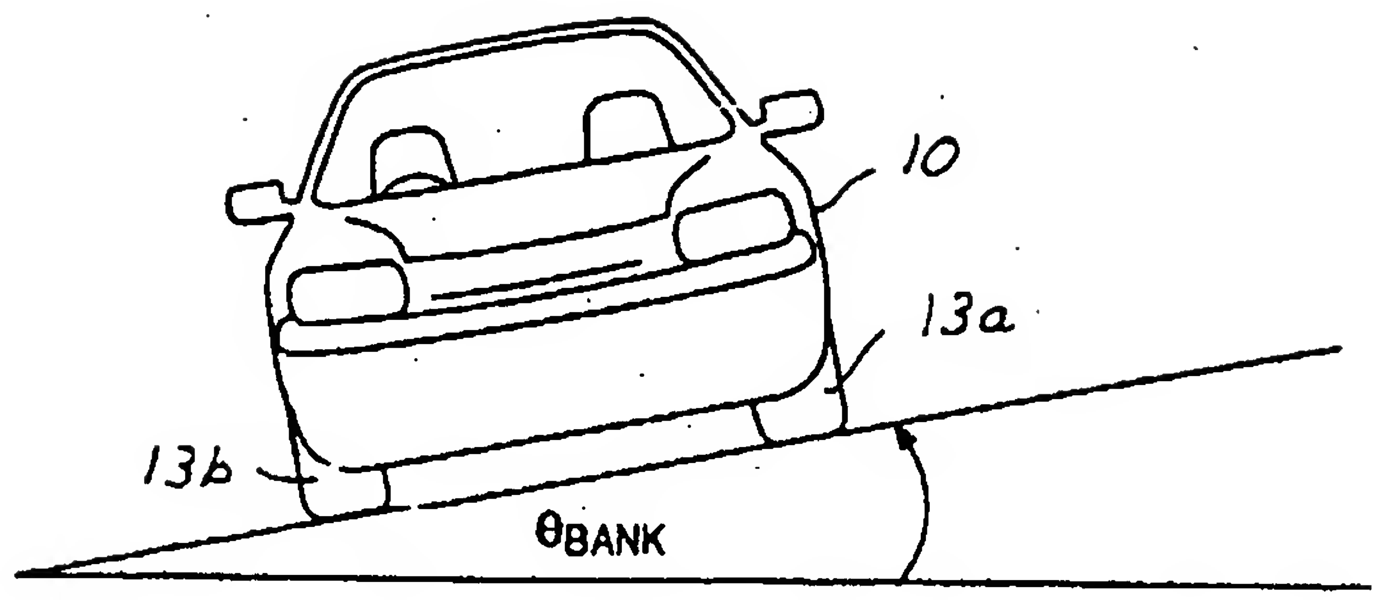

FIG. 2

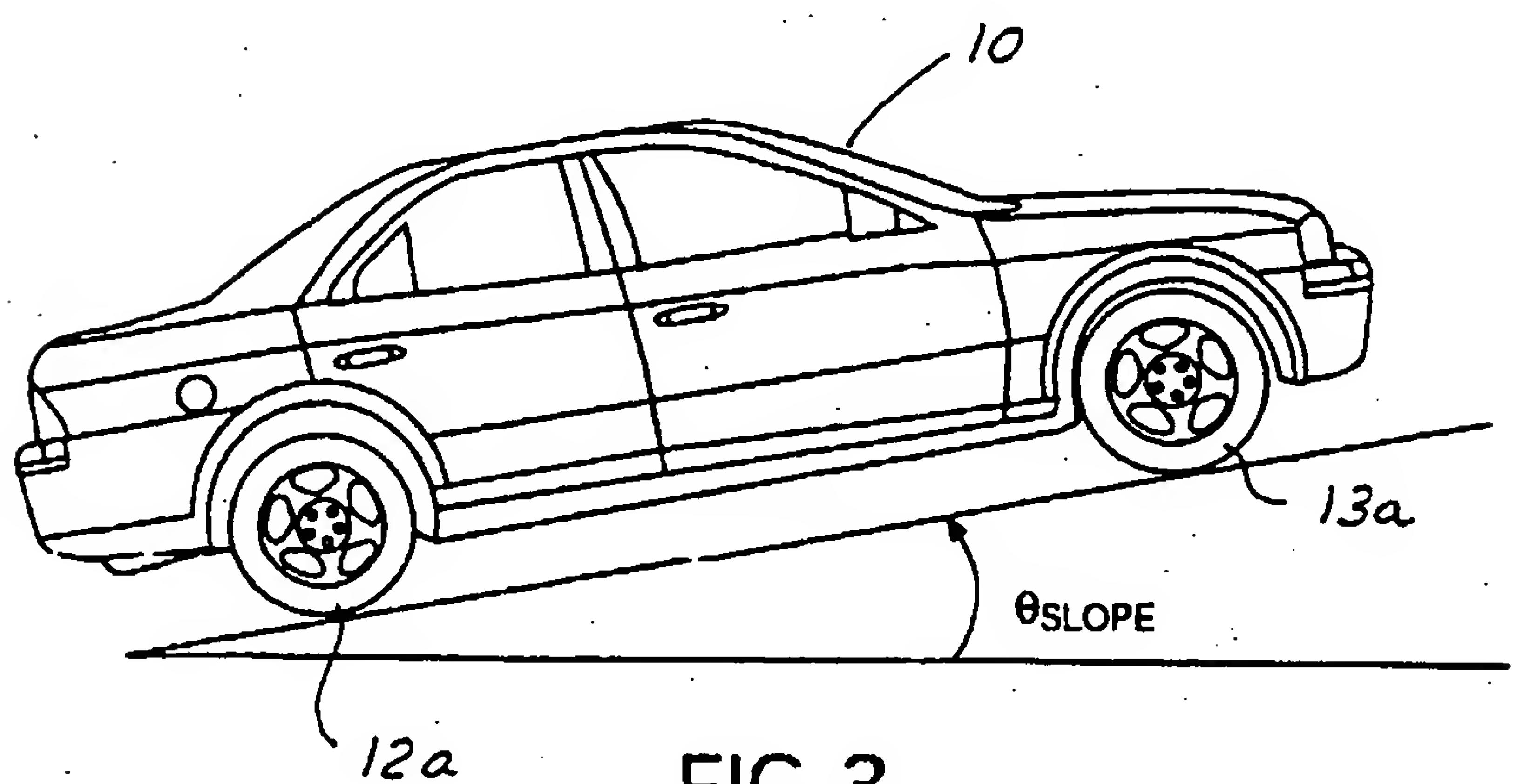

FIG. 3

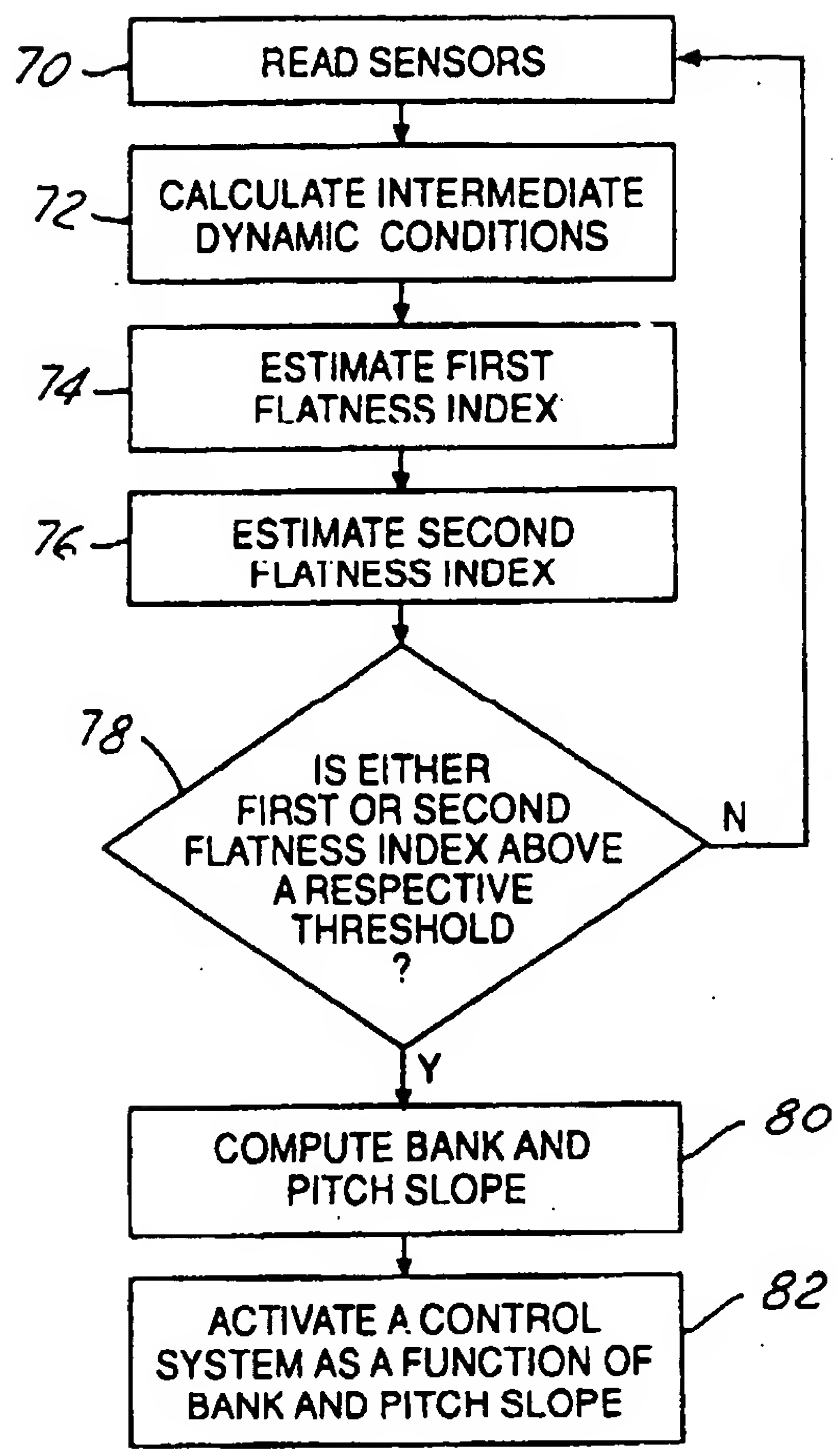
READ SENSORS
CALCULATE INTERMEDIATE DYNAMIC CONDITIONS
ESTIMATE FIRST FLATNESS INDEX
ESTIMATE SECOND FLATNESS INDEX
IS EITHER FIRST OR SECOND FLATNESS INDEX ABOVE A RESPECTIVE THRESHOLD ?
N
Y
COMPUTE BANK AND PITCH SLOPE
ACTIVATE A CONTROL SYSTEM AS A FUNCTION OF BANK AND PITCH SLOPE
70
72
74
76
78
80
82

FIG. 5

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A CONTROL SYSTEM FOR A MOTOR VEHICLE

The present invention relates generally to a control system for an automotive vehicle and more specifically, to a method and system for determining a surface profile of the road on which the vehicle is travelling and using such determination to effect control of the vehicle.

Dynamic control systems for automotive vehicles have recently begun to be offered on various products. Dynamic control systems typically control the yaw of the vehicle by controlling the braking effort at the various wheels of the vehicle. Yaw control systems typically compare the desired direction of the vehicle based upon the steering wheel angle and the direction of travel. By regulating the amount of braking at each corner of the vehicle, the desired direction of travel may be maintained. Typically, the dynamic control systems do not address roll of the vehicle. For high profile vehicles in particular, it would be desirable to control the rollover characteristic of the vehicle to maintain the vehicle position with respect to the road. That is, it is desirable to maintain contact of each of the four tyres of the vehicle on the road.

In vehicle rollover control, it is desired to alter the vehicle attitude such that its motion along the roll direction is prevented from achieving a predetermined limit (rollover limit) with the aid of the actuation from the available active systems such as controllable brake system, steering system and suspension system. Although the vehicle attitude is well defined, direct measurement is usually impossible.

There are two types of vehicle attitudes needed to be distinguished. One is the so-called global attitude, which is sensed by the angular rate sensors. The other is the relative attitude, which measures the relative angular

positions of the vehicle with respect to the road surface on which the vehicle is driven. The global attitude of the vehicle is relative to an earth frame (or called the inertia frame), sea level, or a flat road. It can be directly related to the three angular rate gyro sensors. While the relative attitude of the vehicle measures the relative angular positions of the vehicle with respect to the road surface, which are always of various terrains. Unlike the global attitude, there are no gyro-type sensors which can be directly related to the relative attitude. A reasonable estimate is that a successful relative attitude sensing system utilises both the gyro-type sensors (when the road becomes flat, the relative attitude sensing system recovers the global attitude) and some other sensor signals.

One reason to distinguish relative and global attitude is due to the fact that vehicles are usually driven on a 3-dimensional road surface of different terrains, not always on a flat road surface. Driving on a road surface with a large road bank does increase the rollover tendency, i.e., a large output from the global attitude sensing system might well imply an uncontrollable rollover event regardless of the flat road driving and the 3-D road driving. However driving on a three-dimensional road with moderate road bank angle, the global attitude may not be able to provide enough fidelity for a rollover event to be distinguished.

Vehicular rollover happens when one side of the vehicle is lifted from the road surface with a long duration of time without returning back. If a vehicle is driven on a banked road, the global attitude sensing system will pick up certain attitude information even when the vehicle does not experience any wheel lifting (four wheels are always contacting the road surface). Hence a measure of the relative angular positions of the vehicle with respect to the portion of the road surface on which the vehicle is driven provides more fidelity than global attitude to sense

the rollover event when the vehicle is driven on a road with a moderate bank angle. Therefore it is important to identify road bank condition for proper vehicle rollover stability control.

Another example of detecting road profile could be used in powertrain controls, where the control of the air and fuel combination ratio or fuel ignition timing is such that they match the intention of a driver so as for the driving power or driving speed of the vehicle to match the present driving condition. Although the driver can identify the profile of a driving road and to control the vehicle accordingly, the road condition information has not been directly fed back to powertrain controls, since there is no road condition information detected and used for current vehicle control systems. Hence optimum fuel economy may not be achieved.

US Patent 5,703,776 considers using a gear position sensing member of a transmission, an engine revolution sensing member, a loading degree sensing, a brake pedal operating state sensing to provide a very crude measure of the longitudinal slope of the road surface. This invention provides a much more refined estimation of the road slope using the sensor sets equipped with vehicle dynamics control systems.

In another example, an active roll control system using anti-roll-bar does not respond suitably to the side bank in conventional setting, since the presence of road side bank cannot be detected and the system therefore responds to a side bank as if the vehicle were cornering. This can result in unnecessary power consumption for the active anti-roll-bar system. In order to eliminate this, WO 99/64262 provides a very crude estimation of the road side bank using lateral acceleration sensor and vehicle reference speed.

In a further example, a vehicle driven on a road with a sharp side bank may cause false activation for the yaw stability control system and/or roll stability control system due to the fact that large lateral motion is determined through sensor signals even if the vehicle is driven in steady state condition on the banked road.

It is an object of this invention to provide a system and method for accurately detecting the road side bank and the road longitudinal slope or pitch and to properly activate the vehicle control systems.

According to a first aspect of the invention there is provided a control system for an automotive vehicle having a vehicle body comprising a first angular rate sensor generating a first angular rate signal corresponding to a first angular motion of the vehicle body; a second angular rate sensor generating a second motion signal corresponding to a second angular motion of the vehicle body; a lateral acceleration sensor generating a lateral acceleration signal corresponding to a lateral acceleration of a centre of gravity of the vehicle body; a longitudinal acceleration sensor generating a longitudinal acceleration signal corresponding to the longitudinal acceleration of the centre of gravity of the vehicle body; a wheel speed sensor generating a wheel speed signal corresponding to a wheel speed of the vehicle and a controller coupled to the first angular rate sensor, the second angular rate sensor, the lateral acceleration sensor, the longitudinal acceleration sensor and the wheel speed sensor wherein the controller is operable to determine a first flatness index and a second flatness index from the first angular rate signal, the second angular rate signal, the lateral acceleration signal and the longitudinal acceleration signal and the speed signal and the controller is operable to determine a road slope or pitch angle and a road bank angle in response to the first flatness index and the second flatness index.

One advantage of the invention is that one angular rate sensor such as a pitch rate sensor may be eliminated.

The first angular rate sensor may be one selected from the group of a yaw rate sensor, a pitch rate sensor and a roll rate sensor and the second angular rate sensor comprises is one selected from the group of a yaw rate sensor, a pitch rate sensor and a roll rate sensor, the second sensor being different than the first sensor.

The first angular rate sensor may be a roll angular rate sensor generating a roll angular rate signal corresponding to an roll angular motion of the vehicle body; the second angular rate sensor may be a yaw angular rate sensor generating a yaw rate signal corresponding to a yaw motion of the vehicle body and the controller may be operable to determine a relative pitch angle and relative roll angle as a function of the lateral acceleration signal, the longitudinal acceleration signal and the roll rate signal, determine a first flatness index as a function of the roll angular rate signal, the yaw angular rate signal, the relative roll angle and a relative pitch angle, determine a steady state pitch angle as a function of the vehicle speed and the longitudinal acceleration, determine a steady state roll angle as a function of lateral acceleration, vehicle speed and yaw rate and determine a second flatness index as a function of the steady state pitch angle, the relative pitch angle, the yaw rate, the steady state roll angle and a relative roll angle.

The control system may further comprise a safety system coupled to the controller, the controller generating a control signal to the safety system as a function of the first flatness index and the second flatness index.

The safety system may comprise an active brake control system or may comprise an active rear steering system or may comprise an active front steering system or may comprise an active anti-roll bar system or may comprise an active suspension system.

According to a second aspect of the invention there is provided a method controlling an automotive vehicle comprising estimating a first flatness index indicative of road flatness; estimating a second flatness index indicative of road flatness; determining a road pitch slope in response to the first flatness index and the second flatness index and determining a road bank angle in response to the first flatness index and the second flatness index.

The method may further comprise the step of controlling a safety device as a function of the bank angle and the pitch slope of the driving road.

The safety device may comprise a yaw control system or may comprise a rollover stability control system.

The steps of determining a road pitch slope in response to the first flatness index and the second flatness index and determining a road bank angle in response to the first flatness index and the second flatness index may be performed when the first flatness index and the second flatness index are above a predetermined threshold.

The method may further comprise determining a roll angular rate signal, a yaw angular rate signal, a relative roll angle and a relative pitch angle; wherein the first flatness index is a function of a first flatness index as a function of the roll angular rate signal, the yaw angular rate signal, the relative roll angle and a relative pitch angle.

The method may further comprise determining a steady state pitch angle, a relative pitch angle, a yaw rate, a steady state roll angle and a relative roll angle; wherein the second flatness index is a function of the steady state pitch angle, the relative pitch angle, the yaw rate, the steady state roll angle and a relative roll angle

According to a third aspect of the invention there is provided a method of controlling an automotive vehicle comprising measuring a roll rate of the vehicle body; measuring a lateral acceleration of the vehicle body; measuring the longitudinal acceleration of the vehicle body; measuring the yaw rate of the vehicle body; measuring a vehicle speed; determining a relative pitch angle and relative roll angle as a function of the lateral acceleration, the longitudinal acceleration and the roll rate signal; determining a first flatness index as a function of the roll angular rate, the yaw angular rate, the relative roll angle and a relative pitch angle; determining a steady state pitch angle as a function of the vehicle speed and the longitudinal acceleration; determining a steady state roll angle as a function of lateral acceleration, longitudinal speed and yaw rate; a determining a second flatness index as a function of the steady state pitch angle, the relative pitch angle, the yaw rate, the steady state roll angle and a relative roll angle and generating a control signal as a function of the first flatness index and the second flatness index.

The method may further comprise the steps of determining a road pitch slope in response to the first flatness index and the second flatness index and determining a road bank angle in response to the first flatness index and the second flatness index.

The method may further comprise the step of activating a safety device as a function of the road bank angle and the road pitch angle.

The safety device may comprise one selected from the group consisting of an active brake control system, an active rear steering system, an active front steering system, an active anti-roll bar system, and an active suspension system.

The invention will now be described by way of example with reference to the accompanying drawing of which:-

Figure 1 is a diagrammatic view of a vehicle with variable vectors and coordinator frames according to the present invention;

Figure 2 is an end view of an automotive vehicle on a bank;

Figure 3 is a side view of a vehicle on a pitch slope;

Figure 4 is a block diagram of a stability system according to the present invention; and

Figure 5 is flow chart of the operation according to the present invention.

In the following figures the same reference numerals will be used to identify the same components. The present invention is preferably used in conjunction with a yaw control system or a rollover control system for an automotive vehicle.

However, the present invention may also be used with a deployment device such as airbag or roll bar. The present invention will be discussed below in terms of preferred

embodiments relating to an automotive vehicle moving in a three-dimensional road terrain.

Referring now to Figure 1, an automotive vehicle 10 with a safety system of the present invention is illustrated with the various forces and moments thereon. Vehicle 10 has front right and front left tyres 12a and 12b and rear right tyres and rear left tyres 13a and 13b, respectively. The vehicle 10 may also have a number of different types of front steering systems 14a and rear steering systems 14b including having each of the front and rear wheels configured with a respective controllable actuator, the front and rear wheels having a conventional type system in which both of the front wheels are controlled together and both of the rear wheels are controlled together, a system having conventional front steering and independently controllable rear steering for each of the wheels, or vice versa.

Generally, the vehicle has a weight represented as Mg at the centre of gravity of the vehicle, where $g = 9.8\ m/s^2$ and M is the total mass of the vehicle.

As mentioned above, the system may also be used with active/semi-active suspension systems, anti-roll bar or other safety devices deployed or activated upon sensing predetermined dynamic conditions of the vehicle.

The sensing system 16 is coupled to a control system 18. The sensing system 16 preferably uses a standard yaw stability control sensor set (including lateral acceleration sensor, yaw rate sensor, steering angle sensor and wheel speed sensor) together with a roll rate sensor and a longitudinal acceleration sensor. The various sensors will be further described below.

The wheel speed sensors 20 are mounted at each corner of the vehicle, and the rest of the sensors of sensing system 16 are preferably mounted directly on the centre of gravity of the vehicle body, along the directions x, y and z shown in Figure 1.

As those skilled in the art will recognize, the frame from b_1, b_2 and b_3 is called a body frame 22, whose origin is located at the centre of gravity of the car body, with b_1 corresponding to the x axis pointing forward, b_2 corresponding to the y axis pointing off the driving side (to the left), and b_3 corresponding to the z axis pointing upward. The angular rates of the car body are denoted about their respective axes as w_x for the roll rate, w_y for the pitch rate and w_z for the yaw rate. The present invention calculations preferably take place in an inertial frame 24 that may be derived from the body frame 22 as described below.

The angular rate sensors and the acceleration sensors are mounted on the vehicle car body along the body frame directions b_1, b_2 and b_3, which are the x-y-z axes of the vehicle's sprung mass.

The longitudinal acceleration sensor is mounted on the car body located at the centre of gravity, with its sensing direction along b_1-axis, whose output is denoted as a_x. The lateral acceleration sensor is mounted on the car body located at the centre of gravity, with its sensing direction along b_2-axis, whose output is denoted as a_y.

The other frame used in the following discussion includes the road frame, as depicted in Figure 1. The road frame system $r_1 r_2 r_3$ is fixed on the driven road surface, where the r_3 axis is along the average road normal direction computed from the normal directions of the four tyre/road contact patches.

In the following discussion, the Euler angles of the body frame $b_1b_2b_3$ with respect to the road frame $r_1r_2r_3$ are denoted as q_{xr}, q_{yr} and q_{zr}, which are also called the relative Euler angles.

The present invention estimates the relative Euler angles q_{xr} and q_{yr} based on the available sensor signals and the signals calculated form the measured values.

Referring now to Figure 2, the present invention determines a road bank angle θ_{bank}, which is shown relative to the vehicle 10 on a road surface.

Referring now to Figure 3, the present invention determines a slope or pitch angle θ_{slope}, which is shown relative to the vehicle 10 on the road surface.

Referring now to Figure 4, roll stability control system 18 is illustrated in further detail having a controller 26 used for receiving information from a number of sensors which may include a yaw rate sensor 28, a speed sensor 20, a lateral acceleration sensor 32, a roll rate sensor 34, a steering angle sensor (hand wheel position) 35, a longitudinal acceleration sensor 36, a pitch rate sensor 37 and steering angle position sensor 39.

In the preferred embodiment, only two axial rate sensors are used. When two of these axial rates are known, the other may be derived using other commonly available sensors. Preferably, yaw rate and roll rate are used as the axial rate sensors. Although pitch rate sensor 37 is illustrated, it can be eliminated in the preferred embodiment.

In the preferred embodiment, the sensors are located at the centre of gravity of the vehicle. Those skilled in the

art will recognize that the sensor may also be located off the centre of gravity and translated equivalently thereto.

Lateral acceleration, roll orientation and speed may be obtained using a global positioning system (GPS). Based upon inputs from the sensors, controller 26 may control a safety device 38. Depending on the desired sensitivity of the system and various other factors, not all the sensors 28-39 may be used in a commercial embodiment. Safety device 38 may control an airbag 40, an active braking system 41, an active front steering system 42, an active rear steering system 43, an active suspension system 44, and an active anti-roll bar system 45, or combinations thereof. Each of the systems 40-45 may have their own controllers for activating each one. As mentioned above, the safety system 38 is preferably at least the active braking system 41.

Roll rate sensor 34 and pitch rate sensor 37 may sense the roll condition of the vehicle based on sensing the height of one or more points on the vehicle relative to the road surface. Sensors that may be used to achieve this include a radar-based proximity sensor, a laser-based proximity sensor and a sonar-based proximity sensor.

Roll rate sensor 34 and pitch rate sensor 37 may also sense the roll condition based on sensing the linear or rotational relative displacement or displacement velocity of one or more of the suspension chassis components which may include a linear height or travel sensor, a rotary height or travel sensor, a wheel speed sensor used to look for a change in velocity, a steering wheel position sensor, a steering wheel velocity sensor and a driver heading command input from an electronic component that may include steer by wire using a hand wheel or joy stick.

The roll condition may also be sensed by sensing the force or torque associated with the loading condition of one

or more suspension or chassis components including a pressure transducer in active air suspension, a shock absorber sensor such as a load cell, a strain gauge, the steering system absolute or relative motor load, the steering system pressure of the hydraulic lines, a tyre lateral force sensor or sensors, a longitudinal tyre force sensor, a vertical tyre force sensor or a tyre sidewall torsion sensor.

The roll condition of the vehicle may also be established by one or more of the following translational or rotational positions, velocities or accelerations of the vehicle including a roll gyro, the roll rate sensor 34, the yaw rate sensor 28, the lateral acceleration sensor 32, a vertical acceleration sensor, a vehicle longitudinal acceleration sensor, lateral or vertical speed sensor including a wheel-based speed sensor, a radar-based speed sensor, a sonar-based speed sensor, a laser-based speed sensor or an optical-based speed sensor.

Based on the inputs from sensors 28 through 39, controller 26 determines a roll condition and controls any one or more of the safety devices 40-45.

Speed sensor 30 may be one of a variety of speed sensors known to those skilled in the art. For example, a suitable speed sensor may include a sensor at every wheel that is averaged by controller 26. Preferably, the controller translates the wheel speeds into the speed of the vehicle. Yaw rate, steering angle, wheel speed and possibly a slip angle estimate at each wheel may be translated back to the speed of the vehicle at the centre of gravity. Various other algorithms are known to those skilled in the art. For example, if speed is determined while speeding up or braking around a corner, the lowest or highest wheel speed may not be used because of its error. Also, a transmission sensor may be used to determine vehicle speed.

As mentioned above, θ_{bank} and θ_{slope} are the road side bank angle and longitudinal slope angle experienced by a vehicle driven. These variables are preferably factored into the control algorithm of a rollover stability control system, or a yaw stability control system or other safety systems. Two variables FI_1 and FI_2 are used here, which are called flatness index 1 and flatness index 2. These variables are defined as:

$$FI_1 = \dot{\Theta}_{bank} + \omega_z \Theta_{slope}$$
$$FI_2 = \Theta_{slope} - \omega_z \int_0^t \Theta_{bank}(\tau)d\tau \qquad 1.1$$

where ω_z is the yaw rate of the vehicle. FI_1 and FI_2 have the following properties:

If the road surface is absolutely flat, then both θ_{bank} and θ_{slope} should be zero, hence FI_1 and FI_2 are both zero.

If the road surface is close to perfect flatness, FI_1 and FI_2 should be close to zero.

If the road surface doesn't have longitudinal slope, $FI_1 = 0$ means the road might have zero bank or constant bank.

If further $FI_2 = 0$, then the road must be flat if the yaw rate is non-zero.

Based on the above discussion, a small magnitude for both flatness indices FI_1 and FI_2 does indicate that the road surface under driving is close to a flat surface. To detect when the road is flat, the flatness indices FI_1 and FI_2 are checked using available sensor signals. In the preferred embodiment, the lateral acceleration a_y, the longitudinal acceleration a_x, the roll rate ω_x and yaw rate ω_z, and the calculated vehicle reference velocity V_{ref}. Of course, the

pitch rate or other signals may be used while the other variables may be calculated.

The relative roll and pitch angles between the vehicle car body and the road surface are denoted as θ_{xr} and θ_{yr}, which can be computed using the methods summarized in U.S. Patent Application [Ford invention disclosure 200-1749] filed on March 4, 2002, the disclosure of which is incorporated by reference herein.

If we compute the following at each time instant k

$$RA(k) = a\omega_x(k) - ba_y(k)$$

$$PA(k) = c\omega_y(k) - da_x(k)$$

with properly chosen coefficients a,b,c and d, and an estimated pitch rate $\hat{\omega}_y$ (which is a function of the roll rate, yaw rate, etc.) or a measured pitch rate ω_y then the computation for the relative roll and pitch angles proposed in the above patent application can be conducted as in the following

$$q_{xr}(k+1) = eq_{xr}(k) + f[RA(k+1) + RA(k)]$$
$$q_{yr}(k+1) = gq_{yr}(k) + h[PA(k+1) + PA(k)]$$

with properly chosen coefficients e,f,g and h.

The vehicle body global roll and pitch angles θ_x and θ_y, which are measured with respect to sea level, can be computed as

$$\begin{aligned}\theta_x &= \Theta_{bank} + \theta_{xr}\\ \theta_y &= \Theta_{slope} + \theta_{yr}\end{aligned} \qquad 1.2$$

Notice that, θ_x and θ_y obey the following relationship with reasonable accuracy

$$\dot{\theta}_x \approx \omega_x + \omega_z \theta_y \qquad 1.3$$

The estimated variable $\hat{\Gamma}_1$ is defined based on the roll and yaw rate sensor measurements, and the calculated relative roll and pitch attitudes of the vehicle (which are further calculated from the longitudinal/lateral acceleration sensor measurements, and the roll rate sensor measurement.

$$\hat{\Gamma}_1 = \omega_x + \omega_z \theta_{yr} - \dot{\theta}_{xr} \qquad 1.4$$

At the k-th time instant, the digital implementation of Equation (1.4) can be written as the following

$$\hat{\Gamma}_1(k) = \omega_x(k) + \omega_z(k)\theta_{yr}(k) - \dot{\theta}_{xr}(k) \qquad 1.5$$

Based on (1.2) and (1.3), the flatness index FI_1 can be approximately computed from $\hat{\Gamma}_1$, or say

$$FI_1(k) \approx \hat{\Gamma}_1(k)$$

Considering

$$\begin{aligned} a_x &= \dot{v}_x - \omega_z v_y - g\theta_y \\ a_y &= \dot{v}_y + \omega_z v_x + g\theta_x \end{aligned} \qquad 1.6$$

The steady state roll and pitch attitudes of the vehicle may be defined as

$$\theta_{yss} = \frac{\dot{v}_x - a_x}{g}$$
$$\theta_{xss} = \frac{a_y - \omega_z v_x}{g} \qquad 1.7$$

The estimated variable $\hat{\Gamma}_2$ is based on the steady state roll and pitch attitudes computed in (1.6) and the relative roll and pitch attitude (angle)

$$\hat{\Gamma}_2 = (\theta_{yss} - \theta_{yr}) - \omega_z \int_0^t [\theta_{xss}(\tau) - \theta_{xr}(\tau)]d\tau \qquad 1.8$$

A digital implementation of (1.8) is used in practice. In order to eliminate potential integration drift, an anti-drift-integration filter of the following z-transformation may be used

$$T_{AID}(z^{-1}) = \frac{d(1-z^{-2})}{1 - c_1 z^{-1} + c_2 z^{-2}}$$

If we define

$$\Xi = \int_0^t [\theta_{xss}(\tau) - \theta_{xr}(\tau)]d\tau$$

then by passing

$$\theta_{xss}(k) - \theta_{xr}(k)$$

through this filter, Θ can be computed as the following

$$\begin{aligned}\Xi(k+1) = c_1\Xi(k) - c_2\Xi(k-1) \\ + d[\theta_{xss}(k+1) - \theta_{xr}(k+1)] \\ - d[\theta_{xss}(k-1) - \theta_{xr}(k-1)]\end{aligned} \qquad 1.9$$

and $\hat{\Gamma}_2$ may be then be expressed as the following

$$\hat{\Gamma}_2(k+1) = \theta_{yss}(k+1) - \theta_{yr}(k+1) - \omega_z(k+1)\Xi(k+1) \qquad 1.10$$

By eliminating lateral velocity v_y from (1.6), the following holds

$$\omega_z \int_0^t \theta_x(\tau)d\tau - \theta_y = \omega_z \int_0^t \theta_{xss}(\tau)d\tau - \theta_{yss} \qquad 1.11$$

Thus, the calculated or estimate $\hat{\Gamma}_2$ is equivalent to the flatness index FI_2.

That is, $FI_2(k) = \hat{\Gamma}_2(k)$ at each time instant.

Using the calculated $\hat{\Gamma}_1$ and $\hat{\Gamma}_2$, the following flat road detection logic can be obtained as in the following

if $\hat{\Gamma}_1(k) \le \min_1$ *and* $\hat{\Gamma}_2(k) \le \min_2$
{
road surface is almost flat
}
else if $\hat{\Gamma}_1(k) <= \min_1$ *and* $\hat{\Gamma}_2(k) \ge \max_2$
{
road doesn't have dynamic side bank
quantitatively computing bank / slope
}
else if $\hat{\Gamma}_1(k) >= \max_1$ *and* $\hat{\Gamma}_2(k) \ge \max_2$
{
road has significant side bank / slope
quantitatively computing bank / slope
}
else
{
quantitatively computing bank and slope
}

where max_1 and max_2 are thresholds. When the thresholds are exceeded, the road is not flat. The road pitch angle and the road bank angle may be used in the controlling of a safety device. That is, when the flatness indices are not small enough, the bank and pitch/slope is determined. In order to do so, the previously computed estimates $\hat{\Gamma}_1$ and $\hat{\Gamma}_2$ are used to formulate the following ordinary differential equations.

The following differential equations derived from (1.1) are obtained.

$$\dot{\Theta}_{bank} + \omega_z \Theta_{slope} = \hat{\Gamma}_1$$
$$\Theta_{slope} - \omega_z \int_0^t \Theta_{bank}(\tau) d\tau = \hat{\Gamma}_2 \qquad 1.12$$

In order to solve Θ_{bank} and Θ_{slope} from the differential equation (1.12), Θ_{slope} is eliminated.

$$\dot{\Theta}_{bank} + \omega_z^2 \int_0^t \Theta_{bank}(\tau) d\tau = \hat{\Gamma}_1 + \omega_z \hat{\Gamma}_2 \qquad 1.13$$

If the road bank is computed from (1.13), then the road slope can be expressed as

$$\Theta_{slope} = \hat{\Gamma}_2 + \omega_z \int_0^t \Theta_{bank}(\tau) d\tau \qquad 1.14$$

If we define the yaw angle Ω_t and an intermediate flatness variable as:

$$\Omega_t = \int_0^t \omega_z(\tau) d\tau$$
$$\Gamma = \Gamma_1 + \omega_z \Gamma_2 \qquad 1.15$$

then the road bank angle obeying (1.13) can be expressed as in the following:

$$\Theta_{bank}(t) = \sin(\Omega_t)\int_0^t \Gamma(\tau)\sin(\Omega_\tau)d\tau + \cos(\Omega_t)\int_0^t \Gamma(\tau)\cos(\Omega_\tau)d\tau \qquad 1.16$$

The numerical implementation of the closed-form solution in (1.16) is used in practice. The yaw angle of the vehicle car body Ω_t, as defined in (1.15), may be computed using the following pure integration scheme

$$\Omega(k+1) = \Omega(k) + \omega_z(k+1)\Delta T \qquad 1.17$$

where ΔT is the sampling time of the control system, $\Omega(k+1)$ and $\omega_z(k+1)$ are the values of the yaw angle and the yaw rate sensor at time instant $t=(k+1)\Delta T$.

Since the potential drift problem, (1.17) may not be close to the actual yaw angle. However $\Omega(k+1)$ appears only in $\sin,\cos$ functions, the drifting could be eliminated by using the following congruent mod operation

$$\Omega_g(k+1) = \Omega(k+1) - 2\pi\, floor\{\frac{\Omega(k+1)}{2\pi}\} \qquad 1.18$$

Notice that $\Omega_g(k+1)$ falls always within 0 and 2π. The $floor(\bullet)$ is a function which is the largest integer bounded by the real number $\bullet$. That is,

$$floor(\frac{\Omega(k+1)}{2\pi})$$

always removes out of the portion that are integer times of 2π from $\Omega(k+1)$, and it outputs a quantity with value falling in between 0 and 2π.

This function is common in "C" programming language. The following intermediate variables may be computed.

$$\begin{aligned}\Gamma_{SI}(k+1) &= c_1\Gamma_{SI}(k) - c_2\Gamma_{SI}(k-1) \\ &\quad + d[\Gamma(k+1)\sin(\Omega_g(k+1)) - \Gamma(k-1)\sin(\Omega_g(k-1))] \\ \Gamma_{CI}(k+1) &= c_1\Gamma_{CI}(k) - c_2\Gamma_{CI}(k-1) \\ &\quad + d[\Gamma(k+1)\cos(\Omega_g(k+1)) - \Gamma(k-1)\cos(\Omega_g(k-1))]\end{aligned} \qquad 1.19$$

Using the numerical scheme shown in (1.13), the following computation for the road bank and road slope angles can be provided where Ψ is an intermediate variable.

$$\begin{aligned}\Theta_{bank}(k+1) &= \sin(\Omega(k+1))\Gamma_{SI}(k+1) + \cos(\Omega(k+1))\Gamma_{CI}(k+1) \\ \Psi(k+1) &= \Psi(k) + \Delta T\Theta_{bank}(k+1) \\ \Theta_{slope}(k+1) &= \hat{\Gamma}_2(k+1) + \omega_z(k+1)\Psi(k+1)\end{aligned} \qquad 1.20$$

Referring now to Figure 5, a summary of the method presented above is illustrated in flow chart form. In step 70, the various sensors are read.

In the present example, a roll rate sensor determines the roll rate of the vehicle, a lateral acceleration sensor generates a lateral acceleration signal of the vehicle body, a longitudinal acceleration sensor generates a longitudinal acceleration signal of the vehicle body, a yaw rate sensor generates a yaw rate signal. A longitudinal vehicle velocity or speed is also obtained.

In step 72, a number of intermediate dynamic conditions are determined from he measured sensor signal. The intermediate dynamic conditions may include pitch rate, relative pitch angle, relative roll rate, relative roll angle, steady state pitch angle, steady state roll angle, and global references of the conditions.

In step 74, a first flatness index is calculated from the conditions. This calculation is an estimate as described above.

In step 76, a second flatness index is calculated from the conditions. This calculation is also an estimate as described above.

In step 78 if either the first index or the second index (or both) are above a threshold this indicates the road has a significant side bank or pitch slope. Step 80 is then executed. The bank and pitch slope are computed from the flatness indexes and various dynamic conditions as mentioned above. In step 82, a control system is activated as a function of bank and pitch slope. For example, when the bank and pitch slope are high, this may indicate an off-road condition, not a rollover condition. This may allow the rollover control system to adjust its rollover thresholds accordingly.

Referring back to step 78, if either index is not above their respective thresholds, step 70 is executed.

While particular embodiments of the invention have been shown and described, it will be appreciated that numerous variations and alternate embodiments may occur to those skilled in the art without departing from the scope of the invention.

Claims

1. A control system for an automotive vehicle having a vehicle body comprising a first angular rate sensor generating a first angular rate signal corresponding to a first angular motion of the vehicle body; a second angular rate sensor generating a second motion signal corresponding to a second angular motion of the vehicle body; a lateral acceleration sensor generating a lateral acceleration signal corresponding to a lateral acceleration of a centre of gravity of the vehicle body; a longitudinal acceleration sensor generating a longitudinal acceleration signal corresponding to the longitudinal acceleration of the centre of gravity of the vehicle body; a wheel speed sensor generating a wheel speed signal corresponding to a wheel speed of the vehicle and a controller coupled to the first angular rate sensor, the second angular rate sensor, the lateral acceleration sensor, the longitudinal acceleration sensor and the wheel speed sensor wherein the controller is operable to determine a first flatness index and a second flatness index from the first angular rate signal, the second angular rate signal, the lateral acceleration signal and the longitudinal acceleration signal and the speed signal and the controller is operable to determine a road slope or pitch angle and a road bank angle in response to the first flatness index and the second flatness index.

2. A system as claimed in claim 1 wherein the first angular rate sensor is one selected from the group of a yaw rate sensor, a pitch rate sensor and a roll rate sensor and the second angular rate sensor comprises is one selected from the group of a yaw rate sensor, a pitch rate sensor and a roll rate sensor, the second sensor being different than the first sensor.

3. A system as claimed in claim 1 or in claim 2 wherein the first angular rate sensor is a roll angular rate

sensor generating a roll angular rate signal corresponding to an roll angular motion of the vehicle body; the second angular rate sensor is a yaw angular rate sensor generating a yaw rate signal corresponding to a yaw motion of the vehicle body and the controller is operable to determine a relative pitch angle and relative roll angle as a function of the lateral acceleration signal, the longitudinal acceleration signal and the roll rate signal, determine a first flatness index as a function of the roll angular rate signal, the yaw angular rate signal, the relative roll angle and a relative pitch angle, determine a steady state pitch angle as a function of the vehicle speed and the longitudinal acceleration, determine a steady state roll angle as a function of lateral acceleration, vehicle speed and yaw rate and determine a second flatness index as a function of the steady state pitch angle, the relative pitch angle, the yaw rate, the steady state roll angle and a relative roll angle.

4. A control system as claimed in any of claims 1 to 3 further comprising a safety system coupled to the controller, the controller generating a control signal to the safety system as a function of the first flatness index and the second flatness index.

5. A control system as claimed in claim 4 wherein the safety system comprises an active brake control system.

6. A control system as claimed in claim 4 wherein the safety system comprises an active rear steering system.

7. A control system as claimed in claim 4 wherein the safety system comprises an active front steering system.

8. A control system as claimed in claim 4 wherein the safety system comprises an active anti-roll bar system.

9. A control system as claimed in claim 4 wherein the safety system comprises an active suspension system.

10. A method controlling an automotive vehicle comprising estimating a first flatness index indicative of road flatness; estimating a second flatness index indicative of road flatness; determining a road pitch slope in response to the first flatness index and the second flatness index and determining a road bank angle in response to the first flatness index and the second flatness index.

11. A method as claimed in claim 10 further comprising the step of controlling a safety device as a function of the bank angle and the pitch slope of the driving road.

12. A method as claimed in claim 11 wherein the safety device comprises a yaw control system.

13. A method as claimed in claim 11 wherein the safety device comprises a rollover stability control system.

14. A method as claimed in any of claims 10 to 13 wherein determining a road pitch slope in response to the first flatness index and the second flatness index and determining a road bank angle in response to the first flatness index and the second flatness index are performed when the first flatness index and the second flatness index are above a predetermined threshold.

15. A method as claimed in any of claims 10 to 14 wherein the method further comprises determining a roll angular rate signal, a yaw angular rate signal, a relative roll angle and a relative pitch angle; wherein the first flatness index is a function of a first flatness index as a function of the roll angular rate signal, the yaw angular rate signal, the relative roll angle and a relative pitch angle.

16. A method as claimed in any of claims 10 to 15 further comprising determining a steady state pitch angle, a relative pitch angle, a yaw rate, a steady state roll angle and a relative roll angle; wherein the second flatness index is a function of the steady state pitch angle, the relative pitch angle, the yaw rate, the steady state roll angle and a relative roll angle

17. A method of controlling an automotive vehicle comprising measuring a roll rate of the vehicle body; measuring a lateral acceleration of the vehicle body; measuring the longitudinal acceleration of the vehicle body; measuring the yaw rate of the vehicle body; measuring a vehicle speed; determining a relative pitch angle and relative roll angle as a function of the lateral acceleration, the longitudinal acceleration and the roll rate signal; determining a first flatness index as a function of the roll angular rate, the yaw angular rate, the relative roll angle and a relative pitch angle; determining a steady state pitch angle as a function of the vehicle speed and the longitudinal acceleration; determining a steady state roll angle as a function of lateral acceleration, longitudinal speed and yaw rate; a determining a second flatness index as a function of the steady state pitch angle, the relative pitch angle, the yaw rate, the steady state roll angle and a relative roll angle and generating a control signal as a function of the first flatness index and the second flatness index.

18. A method as claimed in claim 17 wherein the method further comprises the steps of determining a road pitch slope in response to the first flatness index and the second flatness index and determining a road bank angle in response to the first flatness index and the second flatness index.

19. A method as claimed in claim 18 wherein the method further comprises the step of activating a safety device as a function of the road bank angle and the road pitch angle.

20. A method as claimed in claim 19 wherein the step of activating a safety device comprises one selected from the group consisting of an active brake control system, an active rear steering system, an active front steering system, an active anti-roll bar system, and an active suspension system.

21. A control system substantially as described herein with reference to the accompanying drawing.

22. A method substantially as described herein with reference to the accompanying drawing.

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Claims searched: 1 to 20

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Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A		EP 1110835 A2 (FORD) whole document relevant
A		SU 1527022 A1 (BELORUSSIAN POLY) see WPI abstract accession no.1990-183715 /24

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